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The comparison of novel serious games in ADHD screening and early diagnosis

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Abstract

Introduction: Despite the increasing global prevalence of ADHD in children, research predominantly focuses on treatment rather than on screening. There is a pressing need for practical tools to identify this disorder. The objective of this review was to conduct a detailed analysis of the novel games used for ADHD screening and early diagnosis.

Material and methods: Our interest was focused on comparing various aspects, such as effectiveness, types of parameters tested, characteristics of the research group, time consumption, and the kind of equipment necessary to conduct the game. Sources were gathered by exploring terms related to ADHD screening and diagnosis in gaming contexts via several databases. Inclusion criteria focused on papers from 2020 to 2024 in English and openly accessible. Ten clinical studies meeting the criteria were identified, analyzed, and compared in subsequent sections.

Results: Our analysis has revealed that the games under discussion are characterized by distinct mechanics and measure different parameters related to ADHD. The methods of their validation are not standardized. These aspects make it challenging to compare them. Certain games incorporate advanced technologies to enhance the objectivity of the screening process.

Conclusions: The results of our review confirm that the screening effectiveness comparable to that acquired by standardized tests could be obtained using serious games. Individuals with ADHD are at higher risk of addiction, though tailored video games can aid in the treatment of ADHD. However, there is a need to standardize the methodology for assessing the effectiveness of the games under analysis.

Keywords: attention-deficit/hyperactivity disorder, serious games, video games, screening, diagnosis

Streszczenie

Wstęp: Pomimo rosnącej globalnej częstości występowania ADHD u dzieci, badania koncentrują się głównie na leczeniu, a nie na badaniach przesiewowych. Istnieje pilna potrzeba opracowania skutecznych narzędzi ułatwiających identyfikację tego zaburzenia. Celem niniejszego przeglądu było przeprowadzenie szczegółowej analizy nowych gier wykorzystywanych do badań przesiewowych i wczesnej diagnozy ADHD.

Materiał i metody: Nasze zainteresowanie koncentrowało się na porównaniu różnych aspektów, takich jak skuteczność, rodzaje testowanych parametrów, charakterystyka grupy badawczej, czasochłonność i rodzaj sprzętu niezbędnego do przeprowadzenia gry. Źródła zostały zebrane poprzez wyszukiwanie terminów związanych z badaniami przesiewowymi i diagnozą ADHD w kontekście gier za pośrednictwem kilku baz danych. Kryteria włączenia koncentrowały się na artykułach z lat 2020-2024, w języku angielskim i ogólnodostępnych. Dziesięć badań klinicznych spełniających kryteria zostało zidentyfikowanych, przeanalizowanych i porównanych w kolejnych sekcjach.

Dyskusja: Nasza analiza wykazała, że omawiane gry charakteryzują się odmienną mechaniką i mierzą różne parametry związane z ADHD. Metody ich walidacji nie są ustandaryzowane. Aspekty te utrudniają ich porównanie. Niektóre gry

wykorzystują zaawansowane technologie w celu zwiększenia obiektywności procesu badań przesiewowych.

Wnioski: Wyniki naszego przeglądu potwierdzają, że porównywalną skuteczność badań przesiewowych do tej uzyskanej za pomocą standardowych testów można uzyskać za pomocą gier użytkowych. Osoby z ADHD są bardziej narażone na uzależnienie, choć dostosowane gry wideo mogą pomóc w leczeniu ADHD. Istnieje jednak potrzeba standaryzacji metodologii oceny skuteczności analizowanych gier.

Słowa kluczowe: zespół nadpobudliwości psychoruchowej z deficytem uwagi, gry użytkowe, gry wideo, diagnoza, badania przesiewowe

Introduction

Attention deficit hyperactivity disorder (ADHD) is a lifespan neurodevelopmental disorder [1, 2]. It is one of the most prevalent disorders within child and adolescent psychiatry, affecting over 5% of this population [2]. Although ADHD typically first manifests in childhood, it can persist into adolescence and adulthood, at least in terms of impairment [1]. DSM-5 classifies defining symptoms of ADHD into symptoms of inattention and hyperactivity or impulsivity, which outline different presentations of ADHD: predominantly inattentive, predominantly hyperactive/impulsive, combined presentation, and partial remission. Unlike DSM-5 and ICD-10, ICD-11 describes the fundamental characteristics of the disorder without providing an exact age of onset, duration, or number of symptoms. ADHD is known for its heterogeneous presentations, frequent and variable comorbidities, overlap with other disorders, and symptoms that are often dependent on the context and may not always be evident during clinical assessment [1, 2]. ADHD rarely impacts only one area of functioning but affects many aspects of an individual's well-being, including physical health, academic performance, social interactions, and occupational functioning [1]. Research has demonstrated a significant correlation between the increased severity of ADHD symptoms and diminished health-related quality of life (HRQoL) [3]. Consequences of ADHD include increased rates of academic failure, a higher likelihood of addiction problems, and an increased accident risk [4]. The adverse effects of ADHD extend beyond the typical symptoms, negatively affecting the quality of life of both patients and their families [3, 4].

Diagnosis of ADHD requires comprehensive observation and evaluation of behaviors, current and past symptoms, and functional impairments [1, 2]. The current diagnostic standard involves a clinical interview, during which a healthcare professional utilizes scales completed by caregivers and teachers. Consequently, the accuracy of an ADHD diagnosis relies on the clinician's training, experience, and knowledge, as well as their observational and communication skills [4–6]. This reliance on subjective reports introduces potential biases [5–7]. Additionally, the accuracy of the assessment may be compromised by various limitations associated with the questionnaires, such as the possible inaccuracy of responses. For instance, patients might downplay or exaggerate their symptoms for reasons such as seeking access to stimulant medications, justifying poor academic performance, or obtaining various social or academic advantages [6]. In recent years, the concept of ADHD has expanded and become more heterogeneous, increasing the complexity of its diagnosis and treatment. This complexity necessitates greater reliance on clinicians' expertise and experience. Although the neurobiological and genetic foundations of ADHD are undeniable, there remains a lack of biomarkers or objective criteria that could facilitate a reliable, automated diagnostic algorithm for detecting ADHD in individuals [2].

The incidence of ADHD diagnoses among children and adolescents is on the rise. However, there is ongoing debate regarding the extent to which this increase reflects an actual rise in prevalence, improved detection, or diagnostic inflation due to misdiagnosis and overdiagnosis [8, 9]. Overdiagnosis may result from broadening the diagnostic criteria to include ambiguous or mild symptoms, explicitly changing the diagnostic definitions, or implicitly medicalizing behaviors previously considered normal [8]. The absence of homogenous assessment criteria contributes to diagnostic inaccuracy [9, 10]. Several factors influence the diagnosis of ADHD, including the role of parents, school-based factors, intrinsic characteristics of children, and the role of healthcare providers, especially access to healthcare, limited reimbursement for specialized mental health care, differences in clinical approaches, scoring cutoffs, and differences in medical systems across countries [7]. While the advantages of accurate ADHD diagnosis and treatment are well recognized, the potential harms are less frequently acknowledged. Physical and psychosocial harms can affect both patients and their families, while economic and opportunity costs impact society at large. A significant proportion of newly diagnosed cases involves

patients with milder symptoms, where the harms, like adverse effects of medication, might outweigh the benefits of diagnosis and treatment [8].

Multiple studies emphasize the importance of early diagnosis and intervention for ADHD [1, 4, 10–12]. Early identification and the implementation of personalized treatment can substantially reduce the severity and persistence of symptoms [4]. Adults with late diagnosis often struggle with considerably more significant impairments compared to those diagnosed earlier in life [11]. This can also lead to the development of harmful coping mechanisms, such as substance abuse. Early interventions are essential to prevent such adverse outcomes [12]. Given that early diagnosis of ADHD can reduce the long-term impact of the disorder and enhance the quality of life, functionality, and self-esteem, there is ongoing interest in developing programs, games, and game-based tools aimed at facilitating early diagnosis [7].

The utilization of computer game technologies has proven beneficial in identifying the neuropsychological profiles of children with ADHD, as well as in their treatment and rehabilitation. These interventions offer significant advantages over traditional methods by reducing both the cost and time required for diagnosis [3]. Unlike cognitive tests, video games can provide rapid assessments and immediate, accurate scoring [13]. Games offer the additional advantage of engaging children in a way that distracts them from the assessment's objective, reducing the likelihood of intentional behaviors such as faking or guessing appropriate responses on a questionnaire and leading to more natural behavior during evaluation [4, 14]. Implementing these digital tools could establish a more objective classification system for attentional and impulsive behavioral disturbances, addressing the need for rapid screening tests in early detection [10].

While the prevalence of ADHD in children is increasing globally, fewer studies are focusing on screening rather than on treatment [14]. Although numerous nonpharmacological treatment approaches for ADHD have been developed, including the use of robots, serious video games, programs, and game-based tools, research on utilizing these methods for ADHD diagnosis and assessment remains limited [3, 14, 15]. With such knowledge, authors took it upon themselves to explore this promising pathway for ADHD identification. This review aimed to compare the effectiveness and usefulness of the latest serious games used in the screening and early diagnosis of ADHD. Sources were collected by searching the phrases *ADHD and games and screening, attention deficit hyperactivity disorder and game and diagnosis, and attention deficit hyperactivity disorder and game and screening* on the Web of Science, PubMed, Google, and Google Scholar. Only articles published between 2020 and 2024, written in English and with open access, were taken into consideration. The last search was performed on 22.04.2024. Ten clinical studies relevant to the subject of the present work were found using the aforementioned methods, discussed, and analyzed for detailed comparison in the following sections. An in-depth characterization of the issues discussed in each paragraph can be found in *Table 1*.

Game rules and design

Despite referring to the same disorder, the games discussed in this paper differed in scheme and course of action. Nevertheless, several similarities and distinguishing features could be highlighted.

Novel digital games are not detached from the previously widely used screening methods. The neuropsychological tests were used as a base for the development of *Chefamania (e.g., NEUROPSI and ENI tests)* and *Antonyms (Flanker task, the Stop signal task, the Stroop test assessing inhibitory control)* [13, 15, 16]. As a result, validation of listed games was facilitated by comparison to the standardized diagnostic tools.

Several discussed games were inspired by the *go/no-go paradigm*, which is broadly applied to assess the ability to inhibit automatic behaviors [16]. During this test, the participant is asked to respond without delay only in reaction to certain stimuli, and the final score is the result of the calculation of commission, his, and omissions [16]. The exact mechanism of action is apparent in *Attention Slackline*, in the task *Chop* in *Chefmania*, and *Central Building* in *Antonyms* [3, 13, 15].

Pinky-Pigg is an approach to adapting animal models of autoshaping into lacking human studies [10]. The resemblance is visible in terms of a scheme and assignment of the participants into groups depending on their responsiveness (both the level and the object of reaction). The studies show insufficient attention and greater impulsivity in the *sign-trackers* population, which corresponds with the results obtained from the game (*high responders* performed worse in a neuropsychological test) [17, 18]. Another game, *GokEvolution*, is based on neurofeedback, which is a non-medicated therapeutic method with inconclusive effectiveness (one meta-analysis proved merely a slight increase in attention, while other studies showed no significant improvement concerning ADHD symptoms) [19, 20]. A focus on obtaining data to facilitate the diagnosis of the disorder and a reduced number of sessions are the factors distinguishing this trial from other neurofeedback-based studies [20].

The purpose of a few games was to create a virtual setting resembling a child's daily environment. Tasks in *Antonyms* are related to two various daily chores (packing a school back and walking down a road)

commonly challenging to children diagnosed with ADHD [15]. Similarly, during participation in the *EPELI* project, the child is immersed in a lifelike surrounding (which is additionally imitated by the emergence of the distractors and task-irrelevant items) and dealing with routine duties [21]. Natural movements and interactions are also enabled by the VR system [21]. In *Dominic Interactive*, the maximization of the probability that the game's user will identify with the main character (which is markedly related to the player's engagement) was obtained by the modification of its appearance, gender, name, or even the situation they are placed in, to correspond with a

Table 1. The comparison of the discussed games.

The article	Game rules	The number and domain of characteristics determined by the serious game	Required hardware	Number of study participants	Age group	Game time
Delgado-Gómez et al. 2020 [6]	A child has to avoid obstacles during the run of a character. As the game progresses, the quickness and the number of gaps increase.	1 - Inattention (Criterion A1 of DSM-5, determined by the performance of a jump and how shortly it occurs before the obstacle)	Readily available devices (smartphone, tablet, or computer) are required.	32 children diagnosed with ADHD	Children aged 8 -16 years	The test takes approximately 7 minutes.
Crepaldi et al. 2020 [15]	This version of the game consists of two mini-games. In the first one, a child compares two objects emerging on the screen. When the objects are identical, the child should place one of them in a backpack and put it in the trash. In the second one, the child has to move only when the light in the correct shade appears. The player receives information about the correctness of actions.	4 - visual selective attention, prolonged attention (Criterion A1 of DSM-5), inhibition, holding automatic responses (Criterion A2 of DSM-5)	Devices that use a touchscreen (e.g. smartphone or tablet) are required.	30 typically developing children	Children aged 8–11 years	The overall time was 45 min for each section.
Apiquian et al. 2020 [13]	The Chefmania consists of eight mini-games in which a child carries out waiter's or cook's duties. Each assesses different aspects of cognition (e.g. billing evaluates the ability to calculate and select edible objects from those presented on the screen in the task Choosing ingredients - visual recognition).	8 - spatial ability, visual discrimination, ability to focus(Criterion A1 of DSM-5), active memory, selective attention (Criterion A1 of DSM-5), inhibitory control (Criterion A2 of DSM-5), planning, and mathematical operations. The primary skills acquired during the education process are also evaluated.	Readily available devices (computer hardware) are required.	266 children distributed as follows: 81 (30.5%) in the 6–7 years old group 45 (16.9%) in the 8–9 years old group 140 (52.6%) in the 10–12 years old group 30 children diagnosed with ADHD (discriminant validity)	Three age groups: 6–7, 8-9, and 10–12 years olds	The total test time is 20 min, but children can complete it earlier. The mean execution time of the total sample was 13.78 ± 4.66 min.

Serrano-Barroso et al. 2021 [20]	InGokEvolutiona child has to reach and maintain a certain amount of attention (presented as a bar on the screen) to complete a level. The amount of focus required to pass a level increases during the game.	1- level of attention (Criterion A1 of DSM-5)	Android-compatible devices are required to run a game. Neurofeedback is obtained by the use of an inexpensive EEG headset (brain-machine interface).	23 children diagnosed with ADHD 52 typically developing children	Children aged 7-12 years	Approximately 2 min to complete the evolution of the character with a perfect performance.
Serrano-Barroso et al. 2022 [10]	A child has to click once on an image of a piggy bank when coins finally get out from a trembling bag. Different types of stimuli (sounds, movement, changing tones) make the objects attention-grabbing. The amount of acquired coins is visible on the screen.	2 - Inattention and Impulsivity (Criterion A1 and A2 of DSM-5, the participants were divided into groups of high and low responders depending on the amount of clicks they performed)	Android-compatible devices are required.	103 children with no history of neurological disorders	Children aged 4-5 years	The game took 20 minutes.
				23 children diagnosed with ADHD (to evaluate the extent of this tool's capabilities)	Children aged 7–16 years	
Merzon et al. 2022 [21]	Virtual reality and eye-tracking technology are applied to assess a child's performance of daily tasks (e.g. having lunch).	1 - the paper mainly aimed to evaluate the level of visual attention(Criterion A1 of DSM-5). However, the assessment is performed by the comparison of various indicators concerning general performance in the game (e.g. total moves) and data acquired via gaze tracker (e.g. fixation period).	A VR headset and a gaze tracker are required. The performance of the task was supervised via a tablet.	37 children diagnosed with ADHD 36 typically developing children	Children aged 9–13 years	The total duration of the game is 25–35 min.
Pandria et al. 2022 [7]	In Pizza on Time a child has to pass obstacles and additionally gather coins during the pizza delivery. The game consists of different levels and mini-games.	The detailed information about characteristics determining ADHD was not mentioned in the paper. The general evaluation of the performance during the game was made by the usage of machine learning technology.	A readily available device (computer) is required.	18 children diagnosed with ADHD 25 typically developing children	Children aged 7-16 years	At the first stage 30-45 minutes of a game. Then, behavioral observation of the participants through the mADHD360 app, over a period of two weeks. In the second stage, participating in the game for an average span of 10 weeks.

Lee et al. 2022 [14]	A child is asked to follow a path previously presented by a robot but should not begin before the starting signal. The participant also has to discontinue the walk and make a gesture (wave or sit) in reaction to the appearing image of a character. During the game, the skeleton details are gathered.	1 - attention score obtained by the gathering of biometrical (skeletal) data (Criterion A1 of DSM-5)	Kinect sensors, a robot, and a projector are required.	66 children diagnosed with ADHD 181 children with ADHD–RISK 349 typically developing children	Children aged 8-13 years	The completion time for the game varies for each child at every stage.
Kovess-Masfety et al. 2023 [22]	Children are asked to answer yes or no questions concerning their mental health. Each question is visualized by a cartoon image with a child character.	The detailed information about characteristics determining ADHD was not mentioned in the paper. 4 out of 81 questions were proper for ADHD diagnosis.	Readily available devices (smartphone, tablet, or computer) are required.	Validation of the Chinese version of Dominic Interactive: 133 children Survey of primary school children in Tianjin using the Chinese version of Dominic Interactive: 1,479 children	Validation of the Chinese version of Dominic Interactive: Children aged 6-12 years Survey of primary school children in Tianjin using the Chinese version of Dominic Interactive: children attending primary educational institutions	The mean time to complete the game was 18 min.
Teruel et al. 2024 [3]	In Attention Slackline, a child has to click a button only when both flags visible on a screen are identical, enabling a character to move toward the distant peak. The game consists of three sections differing in the complication of the tasks, assessing different cognitive functions. The difficulty (understood as an increasing amount of distractors) elevates with the progression of the game.	8 - pattern identification, divided attention, short-term memory, serial processing, and reaction to multiple impulses (the level of impulsiveness, selective, and sustained focus – Criterion A1 and A2 of DSM-5 - is evaluated by the number of hits, omissions, and commissions)	A gaming desktop is required. An EEG headset, a gazer tracker, and a wristband were also implemented to obtain biometric measurements for future projects. Those devices are non-essential for the usage of the game in its current shape.	36 children diagnosed with ADHD 44 typically developing children	Children aged 6-18 years	Three different levels of AS, each lasting 5 minutes.

cultural context [22, 23]. The importance of this solution is emphasized by the requests from the participants of Antonyms to enable alternation of the hero's presentation [15]. Also, adapting the schemes of well-known games for use in screening, as exemplified by *Pizza on Time* and *Running Racoon*, could enhance the ecological validity of the examination [6, 7].

The increase in difficulty (obtained by the rising

number of distractors/obstacles, increasing pace, or elevated level of required attention) is apparent in several serious games [3, 6, 15, 20]. Another concept was the implementation of multiple segments, each assessing different cognitive functions, enabling directing attention to a single factor at once [13, 15].

A specific storyline and context were included in the design of some games (e.g., in *Chefmania*, a participant has to perform the duties of the restaurant staff; in *Pizza on Time*, is obliged to deliver the order; in *GokEvolution* is responsible for the hero's evolution, in *Attention Slackline* is expected to save a missing person and in *Antonyms* - a kingdom under attack) [3, 7, 13, 15, 20]. The contextualization was meant to give significance to the child's action and to enhance the diagnostic process.

The aim of each of the discussed games was to create an enjoyable and child-focused environment. The designers of *Attention Slackline* emphasized the assurance of a positive outcome message despite the child's performance and rejection of presenting harmful content [3].

The superior purpose of most games described in this article was to objectively explore the presence and intensity of characteristics suggesting an ADHD diagnosis. The subjective character of currently used diagnostic methods (supposedly associated with under- and overdiagnosis of the disorder) was emphasized by the authors [3, 7, 14, 20, 21]. However, the structure of the *Chinese version of Dominic Interactive* resembled a questionnaire adjusted in terms of graphics and sounds to suit electronic devices and stood out from the rest due to its self-assessment nature [22]. Moreover, the authors of this game admit that in the case of externalizing disorders, patients tend to underestimate their symptoms, which supports the judgment about the superiority of the objective approach.

Some of the described games are intended not only to evaluate the features associated with ADHD but also to serve as intervention tools (e.g. *Antonyms* was meant to improve inhibitory processes and *GokEvolution* to practice attention), which could be seen as a prospective approach to the complex management of the disorder [7, 15, 20].

Characteristics determined by the serious game

Both DSM-5 and ICD-11 classifications of mental disorders characterized ADHD as the persistent presence of symptoms in domains of *Inattention* (DSM-5 criteria A1), *Hyperactivity and impulsivity* (DSM-5 criteria A2), *or both* [1]. The serious games created for ADHD screening determined the levels of those characteristics in children. Some intended to assess several features, while others focused entirely on a single domain. *Chefmania* and *Attention Slackline* design provides analysis of the most significant number of cognitive functions by also examining the presence of abnormalities in domains not directly mentioned in the DSM-5 classification but highlighted by numerous studies (e.g., active memory in both games and ability to calculate in *Chefmania*) [3, 13, 19]. Since games using machine learning analyzed general data obtained during the participant's performance or intricate biometrical details, it was hampered to distinguish specific characteristics referring to the classifications of diseases [7, 21]. Identification of ADHD-related qualities was also unobtainable in the case of the game *Dominic Interactive* (precise information concerning this aspect was not mentioned in the publication) [22].

Required hardware

Easily accessible and uncomplicated in-use devices (personal computers, laptops, mobile phones, or tablets) were required to run most games described in this review. Nevertheless, more sophisticated technology gathering biometrical data (which includes EEG headsets, robots, gaze monitoring, VR devices, and body tracking sensors) was also implemented in ADHD screening.

A simplified version of EEG, different from its predecessors regarding mobility, time-effectiveness, and affordability, was utilized in the study investigating the efficacy of GokEvolution [20]. A single electrode placed above the Fp1 position of the frontal lobe, collecting EEG signals with the determination of five sub-frequency bands, adequately assessed participants' attention. EEG data was also gathered during research on Attention Slackline [3].

Two highly advanced types of hardware were used in the study by Lee et al. [1, 14, 24]: a robot (whose functions were rules explanation and guiding participants during a game) and Kinect sensors (intended for skeletal data collection), enabling objective assessment of DSM-5 criteria referring to hyperactivity (e.g., inability to sit still or exhibition of fidgety behavior) [1, 14, 24]. Complex evaluation of the child's joint motion and application of touchless, nonrestrictive detectors could be considered advantages of the applied method [25].

The usage of sight-tracking in ADHD screening is based on various studies, showing differences in eye movement patterns between individuals diagnosed with ADHD (e.g., decreased ability to focus vision on a goal object, reduced control of saccadic motions, and directing gaze on a salient item) and healthy subjects [3, 21]. Implementation of this technology in *Attention Slackline* was aimed at examining whether the player focused their gaze on a target object [3]. In the screening method proposed by Merzon et al. [21], a detailed analysis of eye movement data was performed in a more naturalistic setting.

Study participants

Diversity of research groups

In the studies discussed, the research groups were diverse. Most studies included cohorts of children with ADHD and also involved healthy children for comparison as a control group. However, in contrast to other studies, a study conducted by Lee et al. includes the ADHD–RISK group, as well as the ADHD and typical group. It presents a significant challenge for medical practitioners and professional teachers to discern individuals who may be at ADHD risk. The inclusion of the ADHD-RISK group was intended to create a systematic screening tool for professionals involved in ADHD diagnostics [14]. A study that investigated *the Running Raccoon Game* focused on examining specific cognitive functions during play only among children diagnosed with ADHD. Unlike other studies, this study's emphasis is not on differentiating children with ADHD from those in the control group. Instead, it evaluates the intensity of inattention symptoms present [6]. Conversely, a study conducted by Crepaldi et al. concentrated only on a group of healthy children. In this study, researchers have investigated the correlations between impulsiveness levels as determined by conventional assessments and the impulsiveness ratings obtained through a serious gaming environment [15]. In a study that investigated the *Chefmania* game, children were divided into three age groups: 6–7, 8–9, and 10–12-year-olds, to examine the effect of age on performance [13].

Cohort sizes

The most substantial cohort in the research was recorded in the study that investigated the *Chinese version of the Dominic Interactive (DI)* game. In a comparative analysis, the study evaluated the DI-generated diagnoses against those obtained using the Development and Well-Being Assessment (DAWBA) tool in a cohort of 133 children. Following this assessment, the DI game was administered to a broader population of 1,479 children attending primary educational institutions in Tianjin [22]. The smallest group of participants took part in a study related to the *Antonyms* SG (30 participants) and the *Running Raccoon Game* (32 participants) [15, 6].

Age groups

The majority of research studies involved school-age children. However, the study that investigated the *Pinky-Piggy* video game application concentrated on younger children aged 4 to 5 [10].

Game time

Each discussed game features a different duration. The shortest duration required to complete the game was observed in the *GokEvolution* application (2 minutes with a perfect performance) and the *Running Raccoon Game* (7 minutes) [20, 6]. The longest-lasting research conducted was the two-phase study aimed at assessing the efficacy of the ADHD360 platform. At the first stage, children engaged in the *Pizza on Time* game for an estimated duration of 30-45 minutes. This was followed by behavioral observation of the participants through the mADHD360 app over a period of two weeks. In the second stage, children participated in the game for an average span of 10 weeks [7].

Assessment Scales and Psychologist Involvement

Psychologists and psychiatrists were actively involved in different phases of the research discussed. Clinical psychologists who specialize in children with ADHD have a significant role in the development process of *GokEvolution Application Game* and *Robot–Led ADHD Screening Game* [14, 20]. During the *Attention Slackline Game*, *Antonyms SG*, and *Pinky-Piggy* videogame, each participant was accompanied by a psychologist, while participants in the *Running Raccoon Game* were supervised by a trained psychiatrist [3, 15, 6, 10]. In the *Chefmania* game, a subsample was subsequently assessed by qualified psychologists to obtain data for concurrent validity [13]. In the initial phase of the *Pizza on Time* game, players undergo a short neuropsychological evaluation carried out by an experienced psychologist from the study team. This evaluation comprises six components from the Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V). Following this, the game's second phase involves a phone call between the participants' parents and the evaluating psychologist to review any ADHD-related behaviors influencing the participants' everyday activities [7].

In many of the games discussed in this article, the results obtained after conducting the games were compared with various tests and questionnaires conducted by psychologists and psychiatrists. In the *GokEvolution Application Game*, researchers established a relationship between the attention indices of NSMW and the behavioral metrics of effectiveness and impulsivity derived from the CARAS-R psychological assessment [20]. Results of the *Attention Slackline* game were compared with D2, a gold-standard test used by psychologists to measure attention [3]. Researchers compared the DI diagnostic classifications with the "gold standard" Development and Well-Being Assessment (DAWBA) in the Chinese version of the Dominic Interactive game. Trained child psychiatrists administered the DAWBA to the parents of the children. Additionally, they conducted separate DAWBA interviews with the children's teachers over the phone [22]. In a study that investigated the *Pinky-Piggy* videogame application, ADHD patients were

evaluated using the Child Neuropsychological Mature Questionnaire (CUMANES, TEA). The study scores were compared using the Child Neuropsychological Maturity Questionnaire (CUMANIN, TEA). Each test was conducted separately and overseen by a psychologist [10].

In numerous games, scales for ADHD screening were utilized, often administered by parents and teachers. Parents or caregivers of participants who performed the EPELI VR task were asked to fill in a set of questionnaires: ADHD Rating Scale-IV (ADHD-RS), the Behavior Rating Inventory for Executive Functions (BRIEF), the Child Behavior Checklist (CBCL), and the Executive Questionnaire of Everyday Life (EQELI) [21]. All children who participated in the *Robot–Led ADHD Screening Game* were administered three scales: the DSM–ADHD scale (Diagnostic and Statistical Manual of Mental Disorders-ADHD scale), CBCL (Child Behavior Checklist), and K–ADHDS (Korean ADHD Diagnostic Scale) [14]. Participants who engaged the *Antonyms SG* were administered the Scala per il Disturbo di Attenzione e Iperattività (SDAI), which is the most widely utilized screening tool for ADHD in Italy. Scale is completed by a teacher [15]. During the *Running Raccoon Game*, the corresponding caregiver or legal tutor completed the inattention subscale of the SWAN scale while each child was undergoing the test. The Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Rating Scale (SWAN) is a scale for ADHD screening [6].

Additional benefits

In the *Robot–Led ADHD Screening Game*, the algorithm's performance was enhanced by incorporating a channel attention layer. It helped verify which parts of the waiting stage and the game stage developed for the classification of normal, ADHD–RISK, and ADHD are helpful in the screening and classification of ADHD [14]. The *GokEvolution* application does not need an internet connection during training so that it can be effectively utilized in various locations. Moreover, in this study, the researchers identified groups that are in the limit zone or at the borderline between ADHD and control attentional profiles [20]. In the *Chefmania Game*, the 95% confidence interval for the Impulsivity Control Index across different age groups enables the classification of academic performance into categories. The categories are early elementary years with poor performance, early elementary, mid-elementary, late elementary, and late elementary with high performance. *Chefmania* may serve as a valuable diagnostic tool, providing critical insights into the alignment of a child's academic performance with their age-related expectations. It stands as a potential benchmark for assessing educational attainment in areas where students frequently fall short of the expected standards at the conclusion of their elementary education [13]. The mADHD360 application enables educators, family members, and healthcare professionals to use a community-focused technology to establish a supportive network. Together, they can collect information to reveal the underlying reasons for a child's actions. This enables them to devise a strategy, with the assistance of a healthcare expert, aimed at diminishing or completely stopping the unwanted child's behavior [7]. *The Running Raccoon Game* belongs to a prevalent gaming genre. Comparable titles, including *Subway Surfer* and *Temple Run*, can be easily found and freely downloaded. The widespread recognition of this genre of game fosters a sense of comfort in patients and, therefore, increases its ecological validity. Another advantage is that this video game is designed to run on any conventional desktop or mobile device, enabling assessments to be conducted at no expense during the consultation [6]. The *Chinese version of the Dominic Interactive* game is a diagnostic screening instrument for children that assesses not only ADHD but also six other common childhood disorders, including phobias, conduct disorder, oppositional defiant disorder, separation anxiety disorder, generalized anxiety disorder, and major depressive disorder [22]. The *Attention Slackline* game is also characterized by a broader scope of diagnostic capabilities. The game, designed to study attention in children with ADHD, is also suitable for neurotypical children and those with other conditions that affect attention, including Autism Spectrum Disorder [3]. During the *Antonyms SG*, children receive instantaneous feedback through both visual and auditory messages. This method has been demonstrated to be exceptionally advantageous for individuals diagnosed with ADHD [15]. To understand the underlying mechanisms of ADHD symptoms in everyday settings, the *EPELI VR* task involves children engaging in 13 distinct activities replicating common real-life scenarios. The virtual game setting is designed to resemble a standard apartment, complete with areas such as a child's bedroom, living room, kitchen, the parents' bedroom, and a bathroom [21]. The *Pinky-Piggy* video game application was developed to address the shortage of rapid screening tests in early detection. It also aims to enhance the sharing of knowledge among scientists and medical professionals. This tool is crafted to support the digitization of information, enabling quick visualization and data analysis globally [10].

Therapeutic Design and Diagnostics

It's noted that people with ADHD are more prone to use video games and may be up to three times more likely to develop an addiction [26]. The addiction to games among individuals with ADHD is influenced by a combination of reward system dysregulation, affective issues, social

challenges, and impulsivity. These factors interplay to increase the risk and severity of gaming disorder in this population [27]. ADHD children tend to increase their video game playtime as they get older, particularly in the 10–12 age group, which suggests that early exposure to video games could be a risk factor for developing addiction later on, especially during adolescence [28]. However, video games, when used appropriately, may complement multimodal treatment for ADHD [26, 29].

The development of such games requires a structured approach. This process should involve a focus group discussion with mental health professionals, teachers, parents, computer science experts, and game designers. The User-Centered Design methodology is recommended for developing games, as it involves considering what users expect from the game [26, 30]. It is essential to confirm that the diagnostic tool is suitable for use with children. This involves agreement among experts and testing with the target demographic to ensure the tool's content is valid and appropriate. Games need to be easy to understand, require minimal cognitive load at the baseline, and have a gradual level of difficulty. The game should be designed to be enjoyable for children, with challenges, rules that stimulate creativity, specific goals, a feedback system, and quantifiable outcomes [26, 30]. To prevent distractions, the visual design of the games should be balanced and varied. A more focused and less cluttered visual presentation can help children with ADHD maintain their attention on the task at hand. The physical movements required in the games should be consistent to help improve children's balance control and attention. Too much variation in movement can lead to task failure and disengagement from the training exercise [31]. While exploring new technologies like Virtual Reality (VR), it's important to choose technology cautiously and be aware of potential side effects, such as motion sickness or discomfort [26]. Incorporating active (playing music), passive (listening to music), and interactive (music-making with feedback) music therapy into serious video games designed for ADHD treatment can be beneficial. These approaches can help reduce ADHD symptomatology and enhance task performance. Active music therapy, for instance, has been shown to improve hemispheric synchrony, social skills, aggressivity, and impulsivity. Passive music therapy can enhance academic skills and attention, while the effects often depend on the music genre, tempo, or task difficulty. Effective sound design is crucial for improving the realism and emotional depth of the player experience [32]. It is suggested that future game designs incorporate insights and expertise from a broader range of specialists, including pediatricians and psychiatrists. Expanding the training items to include social interaction skills could also be beneficial [31]. A comprehensive meta-analysis scrutinized the overall diagnostic precision of ADHD screening instruments, revealing their performance surpasses chance expectation; however, notable discrepancies exist among different assessors and demographics. None of the tools satisfied the minimal criteria for acceptable sensitivity and specificity [33].

Utilizing both subjective and objective metrics to forecast an ADHD diagnosis yields advantages, with noteworthy sensitivity and specificity observed in children and adults alike. Objective metrics demonstrate resilience against evaluator bias and inaccuracies inherent in subjective evaluations. Utilizing machine learning techniques, mainly support vector machines (SVM), has shown promise in predicting ADHD diagnoses, suggesting that objective evaluations may outperform subjective accounts in assessing hyperactivity in children [34].

Summary

Most of the games discussed in this dissertation can be characterized as efficacious in distinguishing between individuals with and without ADHD or in ascertaining the severity of symptoms related to ADHD. The efficacy of these games was established through comparison either with a non-ADHD control group or with standardized assessments. Some of these games, such as the Robot-Led ADHD Screening Game, Pizza on Time, Attention Slackline, Dominic Interactive, and EPELI, offer additional advantages [3, 7, 14, 21, 22]. The absence of a standardized approach for assessing the efficacy of the games scrutinized poses challenges in comparing their effectiveness in the realm of ADHD screening. It is noteworthy that certain games, like Attention Slackline, GokEvolution, and Running Raccoon Game, concentrate solely on specific aspects (e.g., attention) rather than addressing the complete range of disorders found in this population [3, 6, 20]. The creators of Dominic Interactive assert that their game is more suitable for diagnosing internalized disorders, potentially limiting its effectiveness in ADHD screening compared to other options discussed [22]. Several studies have underscored the existing limitations and the consequent imperative for enhancement.

To conclude, although conventional ADHD screening tools exhibit satisfactory diagnostic precision, caution should be exercised due to variability and elevated false favorable rates. Integrating subjective and objective metrics, along with leveraging machine learning methodologies, can enhance diagnostic precision. Moreover, game-based screening presents a unique and effective strategy for ADHD screening by furnishing objective behavioral data and involving children in the screening process. Efforts are currently underway to

enhance the precision of ADHD screening instruments through the refinement of diagnostic criteria. This endeavor encompasses the potential integration of said tools into academic environments, such as primary schools, to furnish a more impartial evaluation of a child's performance in activities and tasks [25]. Subsequent research aims to elevate the effectiveness of ADHD screening instruments by leveraging diverse computational models, such as the GCN model tailored for skeleton data. Such an approach has the potential to heighten the precision and dependability of ADHD screening instruments [14]. Endeavors are underway to streamline existing data collection systems, with the prospect of facilitating broader and more frequent utilization of diagnostic instruments across various contexts [14, 25]. A particular emphasis is being placed on the formulation of novel therapeutic approaches that incorporate elements like music to amplify attention and engagement. Additionally, efforts are being directed toward validating gamified cognitive assessments and interventions to ensure the trustworthiness and precision of ADHD evaluations [3]. To substantiate the findings, forthcoming studies should encompass larger sample sizes and employ diverse assessment metrics (objective). Incorporating control groups in prospective research endeavors would enable investigators to scrutinize the game's capacity to differentiate between children with ADHD and those without, thus establishing the diagnostic tool's specificity and sensitivity [6].

Conflict of interest

The authors have declared no conflict of interest.

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